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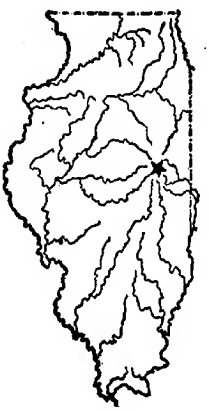
LIMESTONE ACTION ON ACID SOILS

By ROBERT STEWART AND F. A. WYATT



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LIMESTONE ACTION ON ACID SOILS

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Lime, marl, or chalk has been applied to soils for many centuries. The early Romans certainly knew of the value of lime for sour soils, and they probably introduced its use into England at the time of the Roman conquest. There the beneficial effects of liming the soil have long been practiced. From the Rothamsted Experiment Station there is a definite record that as much as 100 tons of chalk per acre had been added a number of years before the beginning of the experimental work on that famous farm.

In America, the beneficial effect of the use of lime has been fully realized only within the last few years. Some of the older experiment stations, among them Pennsylvania, Maryland, and Rhode Island, were the first to demonstrate the benefit derived from liming the soil, and both Pennsylvania and Maryland also emphasized the feasibility of using ground limestone for this purpose. The work of the Illinois Experiment Station[1] has demonstrated the great value of ground limestone on acid soils. There are some questions, however, regarding the use of limestone upon which additional information is needed: viz.,

Can dolomitic limestone be used successfully on acid soils, and what is its value compared with high-calcium limestone?

What is the comparative value of the finely ground material and that more coarsely ground, which can be purchased more cheaply?

What is the durability of the various forms and kinds of lime when applied to soils in the field?

What effect does the application of limestone to the surface have upon the acidity of the subsurface and the subsoil?

What is the annual loss of limestone from the soil, and what are the factors which contribute to this loss?

A number of years ago some work was done at the Edgewood experiment field on some of these problems. The type of soil at Edgewood is gray silt loam on tight clay and belongs to the prairie land of the lower Illinoisan glaciation. This field, which has now been discontinued, consisted of three parts: west field, east field, and north field. The east field was divided into Series 300, which received ground limestone, and Series 400, which received freshly slaked lime.

Ferris,[2] who made a study of the effect of limestone on this field, shows dolomite to be twice as durable as high-calcium limestone; also

[1] Ill. Agr. Exp. Sta. Circs. 110 and 181 and Bul. 193.
[2] Ferris, Thesis: Studies in the Use of Lime and Limestone, 1912.

that hydrated lime caused a loss per acre per annum of 192 pounds more nitrogen and 2,529 pounds more carbon from the upper twenty inches of soil than did ground limestone. Hopkins,[1] comparing Ferris' averages of eight treated plots and eight untreated, computes that 780 pounds of limestone are lost from the upper twenty inches of soil per acre per year.

RESULTS FROM THE NEWTON EXPERIMENT FIELD

Investigations to determine the influence of forms, amounts, and degree of fineness of limestone were begun in 1912 on the University experiment field located about one mile west of Newton, in Jasper county. The soil is gray silt loam on tight clay and belongs to the prairie land of the lower Illinoisan glaciation. The land is practically level, having a fall of only a few feet in the entire length of the field. The outline of the investigations and the treatment of the various plots are shown in the accompanying plan.

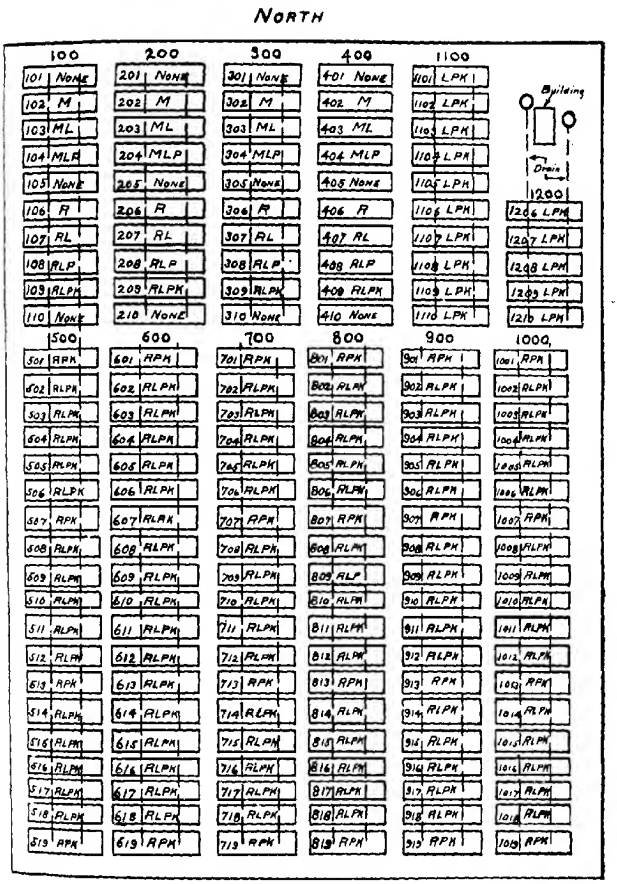
In Series 100, 200, 300, and 400, which are devoted to grain and live-stock systems of farming, Plots 1, 5, and 10 are check plots, receiving no treatment. Plots 3, 4, 7, 8, and 9 receive dolomitic limestone (¼-inch mill-run, that is, from ¼ inch down to dust) at the rate of 3,000 pounds per acre, the application being made every third year for the legume. To Plots 2, 3, and 4 manure is applied for corn once during the rotation, and in proportion to the crops produced. Plots 6, 7, 8, and 9 receive organic matter in the form of the crop residues and cover crops grown upon these plots. Plots 4, 8, and 9 receive phosphorus in fine-ground, raw rock phosphate, while Plot 9 also receives potassium in kainit. Series 100, 200, and 300 are tile-drained, while Series 400 is not tiled. The rotation in these four series is: (1) corn, (2) soybeans (or cowpeas), and (3) wheat, with a legume cover crop (sweet clover) seeded in the wheat on Plots 6, 7, 8, and 9, which are devoted to the grain system. Series 400 always grows the same crop as Series 200, and also receives the same application of limestone applied at the same time.

The amounts and dates of the applications of limestone are recorded in Table 1.

TABLE 1.—LIMESTONE APPLIED ON SERIES 100, 200, 300, 400: NEWTON FIELD
(Pounds per acre)

Series	1912	1913	1914	1915	Total
100	1 000	3 000	.....	....	4 000
200	2 000	....	3 000	....	5 000
300	3 000	....	....	3 000	6 000
400	2 000	....	3 000	....	5 000

[1]Hopkins, Ill. Agr. Exp. Sta., Soil Report 3, page 8.



PLAN OF NEWTON EXPERIMENT FIELD

EFFECT OF LIMESTONE ON THE SURFACE SOIL (Series 100 to 400)

In May, 1916, about three and one-half years after the application of limestone was begun, samples of soil were obtained from each plot for analysis for limestone and acidity. Samples were taken from the surface (0 to 6⅔ inches), the subsurface (6⅔ to 20 inches), and the subsoil (20 to 40 inches). Composite samples were obtained by taking twelve borings from each plot. The acidity was measured in terms of pure limestone (calcium carbonate) required to neutralize it; and the limestone present was also reported in terms of calcium carbonate, as measured by the carbon dioxid liberated by strong acid.

The effect of the application of limestone on the surface soil of these series may be seen from a study of the data recorded in Table 2. The limestone applied had not yet destroyed all the acidity in the surface soil, altho in all plots it had materially reduced the amount present and in most cases had destroyed almost all the acidity present. On the other hand, in all plots on which limestone had been applied a considerable amount was still present in the soil. Even in Series 100, where the latest application had been made in 1913 and where the total application had been only 4,000 pounds, the average amount of limestone remaining in the soil in 1916 was 881 pounds per acre; that is, two and one-half years after the latest application of limestone to this series, appreciable amounts of applied limestone could still be found in the surface soil of the limed plots, while an average of 563 pounds of acidity per acre had been destroyed and an average of 487 pounds of acidity still remained. Computations bringing out similar facts may be made for the other series. The amount of limestone which had been destroyed or lost, either by neutralizing acidity present or by being carried off in the drainage as soluble salts of calcium and magnesium, was considerable.

The amount of acidity found in the soil of the untreated plots varied from plot to plot; for example, from 918 pounds on Plot 101 to 1,808 pounds on Plot 102, so that too much importance should not be attached to the figures from individual plots.

TABLE 2.—EFFECT OF LIMESTONE ON SURFACE SOIL, SERIES 100 TO 400: NEWTON FIELD, 1916

Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Plot No.	Treatment	Limestone added		Soil acidity		Limestone	
		Degree of fineness	Amount, *lbs.*	Destroyed	Found	Amount found	Annual loss
Series 100							
101	0	.....	....	....	918	....	....
102	M	.....	....	....	1 808	....	....
103	ML	¼ inch down	4 000	215	948	404	966
104	MLP	¼ inch down	4 000	531	632	896	735
105	0	.....	....	....	763	....	....
106	R	.....	....	....	1 018	....	....
107	RL	¼ inch down	4 000	456	518	997	728
108	RLP	¼ inch down	4 000	852	122	979	619
109	RLPK	¼ inch down	4 000	760	214	1 131	602
110	0	.....	....	....	1 140	....	....
Series 200							
201	0	.....	....	....	2 120	....	....
202	M	.....	....	....	2 368	....	....
203	ML	¼ inch down	5 000	1 951	330	1 556	426
204	MLP	¼ inch down	5 000	2 152	130	1 817	295
205	0	.....	....	....	2 356	....	....
206	R	.....	....	....	2 114	....	....
207	RL	¼ inch down	5 000	2 051	180	1 458	426
208	RLP	¼ inch down	5 000	2 089	142	1 888	291
209	RLPK	¼ inch down	5 000	2 181	50	1 808	289
210	0	.....	....	....	2 224	....	....
Series 300							
301	0	.....	....	....	2 552	....	....
302	M	.....	....	....	2 304	....	....
303	ML	¼ inch down	6 000	2 132	142	2 450	404
304	MLP	¼ inch down	6 000	2 132	142	3 174	198
305	0	.....	....	....	1 968	....	....
306	R	.....	....	....	1 752	....	....
307	RL	¼ inch down	6 000	1 531	252	3 613	245
308	RLP	¼ inch down	6 000	1 691	92	3 827	137
309	RLPK	¼ inch down	6 000	1 560	222	3 017	406
310	0	.....	....	....	1 628	....	....
Series 400							
401	0	.....	....	....	964	....	....
402	M	.....	....	....	598	....	....
403	ML	¼ inch down	5 000	707	142	1 122	906
404	MLP	¼ inch down	5 000	746	102	1 852	686
405	0	.....	....	....	984	....	....
406	R	.....	....	....	1 530	....	....
407	RL	¼ inch down	5 000	930	138	3 051	291
408	RLP	¼ inch down	5 000	927	141	3 265	231
409	RLPK	¼ inch down	5 000	684	384	965	958
410	0	.....	....	....	690	....	....

TABLE 2.—*Concluded*

Plot No.	Treatment	Limestone added		Soil acidity		Limestone	
		Degree of fineness	Amount, *lbs.*	Destroyed	Found	Amount found	Annual loss
	Average of Results from All Four Series						
1	0.....	.....	....	....	1 638	....	....
2	M.....	.....	....	....	1 769	....	....
3	ML.....	¼ inch down	5 000	1 251	390	1 382	675
4	MLP.....	¼ inch down	5 000	1 390	254	1 935	478
5	0.....	.....	....	....	1 518	....	....
6	R.....	.....	....	....	1 604	....	....
7	RL.....	¼ inch down	5 000	1 242	272	2 279	422
8	RLP.....	¼ inch down	5 000	1 389	124	2 489	319
9	RLPK.....	¼ inch down	5 000	1 296	217	1 730	563
10	0.....	.....	....	....	1 420	....	....

EFFECT OF DRAINAGE UPON LOSS OF LIMESTONE

(Series 100 to 400)

The data showing the effect of drainage on loss of limestone are summarized in Table 3.

Comparing the drained portion of the field with the undrained portion, there is found, as an average of all limestone-treated plots of Series 100, 200, and 300 (drained), 1,934 pounds per acre of limestone and 1,485 pounds of acidity destroyed and an annual loss from the surface soil of 435 pounds of limestone; whereas in Series 400 (undrained) there is found 2,051 pounds per acre of limestone present and 799 pounds of acidity destroyed, and an annual loss of 614 pounds of limestone. However, there is as great a difference between any two of the drained series as between the drained and the undrained series. Thus, Series 100 shows, as an average, 881 pounds per acre of limestone present, 563 pounds of acidity destroyed, and an annual loss of 730 pounds per acre, while Series 300 shows 3,216 pounds of limestone present, 1,809 pounds of acidity destroyed, and an annual loss of

TABLE 3.—EFFECT OF DRAINAGE UPON LOSS OF LIMESTONE, SERIES 100 TO 400: NEWTON FIELD, 1916

Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

	Drained				Undrained	General average
Series.....	100	200	300	Average	400	
Limestone applied.....	4 000	5 000	6 000	5 000	5 000	5 000
Limestone found.....	881	1 705	3 216	1 934	2 051	1 964
Acidity destroyed.....	563	2 084	1 809	1 485	799	1 314
Total limestone accounted for.....	1 444	3 789	5 025	3 419	2 850	3 277
Annual loss from surface soil.....	730	345	278	435	614	491

278 pounds of limestone. Series 100 received but 4,000 pounds of limestone, while Series 300 received 6,000 pounds. Series 200 and 400 each received 5,000 pounds; but Series 200 shows an average of 1,705 pounds of limestone present, 2,084 pounds of acidity destroyed, and an annual loss of 345 pounds, compared with 2,051 pounds of limestone present and 799 of acidity destroyed, and an annual loss of 614 pounds of limestone for Series 400, which had not been drained.

From the above data it may be seen that the variations between the series are greater than the difference between the drained and the undrained land, and that no conclusion is yet justified as to the effect of drainage upon the loss of limestone from this type of soil.

INFLUENCE OF APPLICATIONS OF LIMESTONE TO SURFACE SOIL UPON ACIDITY IN THE SUBSURFACE AND SUBSOIL

(Series 100 to 400)

The data for limestone and acidity present in the subsurface of Series 100 to 400 are recorded in Table 4. There is some evidence that the limestone applied to the surface penetrated into the subsurface and destroyed some subsurface acidity (an average of 1,017 pounds per acre) during the time that had elapsed since the initial application, but the plot variations are so great as to give plus and minus quantities even in the serial averages, and this renders the final average less trustworthy. There is also evidence that the native limestone, often found in the subsoil, in some places extended upward into the subsurface.

The data for limestone and acidity present in the subsoil may be found in Table 5. The irregularity of the results, together with the

TABLE 4.—EFFECT OF LIMESTONE ON SUBSURFACE, SERIES 100 TO 400: NEWTON FIELD, 1916

Average pounds calcium carbonate in 4 million pounds of subsurface soil (one acre about 6⅔ to 20 inches deep)

Plot No.	Series....	100	200	300	400	100	200	300	400	Average
	Treatment	Limestone found				Acidity found				
1	0.....	..	..	..	..	4 944	9 348	7 388	6 888	7 142
2	M.....	..	..	..	..	6 100	6 892	6 808	8 400	7 050
3	ML.....	..	..	380	94	8 624	5 876	6 624	9 980	7 776
4	MLP.....	..	514	524	..	6 464	5 876	4 604	6 688	5 908
5	0.....	..	..	2 356	..	2 292	6 488	2 708	7 012	4 625
6	R.....	..	..	..	..	980	6 404	5 724	6 092	4 800
7	RL.....	346	..	490	926	736	5 712	3 644	2 832	3 231
8	RLP.....	..	686	662	410	204	5 652	3 140	904	2 475
9	RLPK....	174	482	754	..	2 164	5 828	2 852	492	2 834
10	0.....	..	..	..	..	3 660	6 276	4 204	644	3 696
Average for limed plots.....						3 638	5 789	4 173	4 179	4 445
Average for unlimed plots.....						3 595	7 082	5 366	5 807	5 462
Acidity destroyed.....						(-43)	1 293	1 193	1 628	1 017

fact that limestone was found in most of the check plots, indicates clearly that the presence of limestone in this stratum was due entirely to its native occurrence and not at all to the applications made to the surface soil.

TABLE 5.—EFFECT OF LIMESTONE ON SUBSOIL, SERIES 100 TO 400: NEWTON FIELD, 1916

Average pounds calcium carbonate in 6 million pounds of subsoil (one acre about 20 to 40 inches deep)

Series.....		100	200	300	400	100	200	300	400
Plot No.	Treatment	Limestone found				Acidity found			
1	0.....	...	468	816	...	23 868	38 424	32 454	17 058
2	M.....	...	834	...	1 140	26 580	36 006	28 032	11 514
3	ML.....	...	1 194	666	468	25 932	39 360	25 502	3 876
4	MLP....	984	576	714	5 550	8 682	28 254	22 866	156
5	0.....	7 428	360	462	4 146	546	24 576	13 644	...
6	R.....	26 652	...	462	3 210	246	18 756	13 722	174
7	RL.....	26 418	1 398	3 876	17 052	...	26 094	978	...
8	RLP.....	7 782	...	5 820	26 754	...	25 302	216	...
9	RLPK...	2 862	234	5 412	30 216	156	29 682	552	...
10	0.....	2 076	828	8 664	13 626	216	28 008	186	...

COMPARATIVE VALUE OF HIGH-CALCIUM AND DOLOMITIC LIMESTONE

(Series 500 to 1000)

From Series 500 to 1000 data were gathered from which to study the comparative effects of applications of high-calcium and dolomitic limestone, together with the effects of the various grades of fineness of limestone, including burnt lime. On these series the rotation is: (1) corn, (2) soybeans (or cowpeas), and (3) wheat, with the legume cover crop (sweet clover). These six series are arranged in three groups of two pairs each. The same crop is grown on the two series of each pair. Thus, in the year in which corn occurs on Series 500 and 600, soybeans are on Series 700 and 800 and wheat on Series 900 and 1000. In Series 500, 700, and 900, the limed plots receive high-calcium limestone or burnt lime, while in Series 600, 800, and 1000 they receive dolomitic limestone or dolomitic burnt lime. Plots 1, 7, 13, and 19 of each series receive no lime treatment. Plots 2 to 6 receive a light application equivalent to 500 pounds per acre per year of pure calcium carbonate, while Plots 8 to 12 receive a medium application of twice this amount, and Plots 14 to 18 receive a large application of four times this amount. In other words, the applications are made on the basis of the equivalent of 500, 1,000, and 2,000 pounds of pure calcium carbonate per acre per annum; three times these amounts being applied every third year. The amounts of limestone applied to these series, together with the dates of application,

are recorded in Table 6. The degree of fineness of the limestone applied is given below:

Plots 2, 8, 14 receive ¼ inch down (mill-run)
" 3, 9, 15 " ¼ inch to $\frac{1}{10}$ inch
" 4, 10, 16 " $\frac{1}{10}$ inch down
" 5, 11, 17 " $\frac{1}{50}$ inch down
" 6, 12, 18 " burnt lime

All plots in these series receive uniform applications of rock phosphate, kainit, and crop residues, including the cover crops plowed under.

TABLE 6.—LIMESTONE APPLIED ON SERIES 500 TO 1000: NEWTON FIELD
(Pounds per acre)

Series	Year				Total
	1912	1913	1914	1915	
Light Application: Plots 2 to 6					
500	500	1 500	....	....	2 000
600	500	1 500	....	....	2 000
700	1 000	....	1 500	....	2 500
800	1 000	....	1 500	....	2 500
900	1 500	....	....	1 500	3 000
1000	1 500	....	....	1 500	3 000
Medium Application: Plots 8 to 12					
500	1 000	3 000	....	....	4 000
600	1 000	3 000	....	....	4 000
700	2 000	....	3 000	....	5 000
800	2 000	....	3 000	....	5 000
900	3 000	....	....	3 000	6 000
1000	3 000	....	....	3 000	6 000
Heavy Application: Plots 14 to 18					
500	2 000	6 000	....	....	8 000
600	2 000	6 000	....	....	8 000
700	4 000	....	6 000	....	10 000
800	4 000	....	6 000	....	10 000
900	6 000	....	....	6 000	12 000
1000	6 000	....	....	6 000	12 000

Samples of soil for analysis were taken in 1916. The data obtained are arranged in Table 7. As will be seen from this table, the plots receiving no lime (1, 7, 13, and 19) showed much variation in soil acidity; but, as an average, the original acidity seems to have been slightly higher in that part of the field where the heavier applications of limestone had been made, especially on Series 500 to 800.

In Table 8 the data appearing in Table 7 are summarized for convenience of study. These results were obtained by averaging data from all plots receiving equivalent applications, irrespective of the degree of fineness. Each serial number, then, is the average of the results from five separate plots. Thus, the general averages are based upon forty-five separate plots; and these results, therefore, are rea-

TABLE 7.—EFFECT OF FORM, AMOUNT, AND DEGREE OF FINENESS OF LIMESTONE UPON SURFACE SOIL: NEWTON FIELD, 1916

Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Series			500	600	500	600	500	600	500	600
Lime applied			High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic
Plot No.	Degree of fineness	Amount, *lbs.*	Limestone found		Soil acidity found		Soil acidity destroyed		Annual loss of limestone	
1	No lime	....	....	....	1 118	1 250	....	....	....	....
2	¼ inch down	2 000	112	493	408	438	759	758	322	214
3	¼ to 1/10 inch	2 000	262	919	438	632	780	512	273	163
4	1/10 inch down	2 000	None	611	436	366	833	726	333	190
5	1/50 inch down	2 000	None	51	508	224	812	816	339	324
6	Burnt lime	2 000	24	19	598	548	773	440	343	440
7	No lime	....	....	....	1 422	934	....	....	....	....
8	¼ inch down	4 000	958	1 511	762	530	806	478	639	574
9	¼ to 1/10 inch	4 000	1 010	2 089	294	428	1 420	752	450	331
10	1/10 inch down	4 000	196	679	508	500	1 352	652	701	762
11	1/50 inch down	4 000	314	135	518	396	1 488	828	628	867
12	Burnt lime	4 000	78	303	936	142	1 216	1 154	773	726
13	No lime	....	....	....	2 298	1 368	....	....	....	....
14	¼ inch down	8 000	2 464	2 385	174	212	2 125	1 362	974	1 215
15	¼ to 1/10 inch	8 000	2 346	4 253	244	82	2 055	1 698	1 029	585
16	1/10 inch down	8 000	1 072	2 591	540	82	1 759	1 904	1 476	1 000
17	1/50 inch down	8 000	1 036	1 657	482	234	1 817	1 958	1 471	1 253
18	Burnt lime	8 000	882	645	172	162	2 127	2 236	1 426	1 462
19	No lime	....	....	....	2 300	2 602	....	....	....	....

TABLE 7.—*Continued*

Series			700	800	700	800	700	800	700	800
Lime applied			High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic
Plot No.	Degree of fineness	Amount, *lbs.*	Limestone found		Soil acidity found		Soil acidity destroyed		Annual loss of limestone	
1	No lime	....	....	....	478	568	....	....	....	....
2	¼ inch down	2 500	874	576	72	228	460	506	333	406
3	¼ to 1/10 inch	2 500	1 182	1 274	112	100	478	800	240	122
4	1/10 inch down	2 500	736	794	202	224	446	841	376	247
5	1/50 inch down	2 500	178	158	178	446	528	786	312	444
6	Burnt lime	2 500	634	None	192	708	572	688	370	517
7	No lime	....	....	....	820	1 562	....	....	....	....
8	¼ inch down	5 000	2 972	1 734	None	468	901	1 154	322	603
9	¼ to 1/10 inch	5 000	2 036	2 304	82	125	898	1 559	590	325
10	1/10 inch down	5 000	1 108	1 056	40	954	1 019	792	821	901
11	1/50 inch down	5 000	464	1 090	344	962	796	846	1 068	875
12	Burnt lime	5 000	656	240	102	828	1 114	1 042	923	1 062
13	No lime	....	....	....	1 298	1 930	....	....	....	....
14	¼ inch down	10 000	4 381	4 361	Alkaline	Alkaline	1 258	1 914	1 246	1 064
15	¼ to 1/10 inch	10 000	3 521	7 381	Alkaline	Alkaline	1 221	1 900	1 502	205
16	1/10 inch down	10 000	5 321	4 741	Alkaline	Alkaline	1 186	1 887	998	963
17	1/50 inch down	10 000	3 821	6 671	Alkaline	Alkaline	1 147	1 872	1 437	416
18	Burnt lime	10 000	1 827	2 048	Alkaline	Alkaline	1 111	1 858	2 017	1 741
19	No lime	....	....	....	1 074	1 844	....	....	....	....

TABLE 7.—*Concluded*

Series			900	1000	900	1000	900	1000	900	1000
Lime applied			High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic
Plot No.	Degree of fineness	Amount, *lbs.*	Limestone found		Soil acidity found		Soil acidity destroyed		Annual loss of limestone	
1	No lime	....	....	....	710	1 074	....	....	....	....
2	¼ inch down	3 000	332	1 314	264	324	508	795	617	254
3	¼ to 1/10 inch	3 000	1 518	1 752	182	670	654	494	236	215
4	1/10 inch down	3 000	568	1 078	244	458	656	751	507	334
5	1/50 inch down	3 000	448	796	670	670	294	584	645	463
6	Burnt lime	3 000	620	1 058	162	162	866	1 137	432	230
7	No lime	....	....	....	1 094	1 344	....	....	....	....
8	¼ inch down	6 000	1 178	1 326	202	224	789	1 052	1 152	1 035
9	¼ to 1/10 inch	6 000	3 040	2 226	142	264	748	944	632	808
10	1/10 inch down	6 000	906	2 204	60	142	729	1 008	1 247	796
11	1/50 inch down	6 000	566	1 388	446	142	242	930	1 483	1 052
12	Burnt lime	6 000	938	1 678	82	None	505	1 004	1 302	933
13	No lime	....	....	....	486	934	....	....	....	....
14	¼ inch down	12 000	3 549	6 258	42	40	634	916	2 233	1 379
15	¼ to 1/10 inch	12 000	4 983	6 176	None	60	866	916	1 757	1 402
16	1/10 inch down	12 000	2 823	4 802	None	40	1 056	956	2 320	1 782
17	1/50 inch down	12 000	4 195	3 894	102	None	1 144	1 016	1 903	2 025
18	Burnt lime	12 000	2 865	2 666	None	None	1 436	1 036	2 199	2 371
19	No lime	....	....	....	1 626	1 054	....	....	....	....

TABLE 8.—COMPARATIVE EFFECT OF HIGH-CALCIUM AND DOLOMITIC LIMESTONE (INCLUDING BURNT LIME). SERIES 500 TO 1000: NEWTON FIELD, 1916

Average pounds calcium carbonate in 2 million pounds of surface soil (about 0 to 6⅔ inches deep)

Series	500	600	700	800	900	1000	Average of all series			
Lime applied	High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic	High calcium	Dolomitic
	Limestone Found								Annual loss	
Light application	79	418	721	560	697	1 198	499	725	392	304
Medium application	511	943	1 449	1 285	1 325	1 764	1 095	1 330	849	777
Heavy application	1 560	2 306	3 774	5 040	3 683	4 759	3 005	4 035	1 599	1 258
Average annual loss									946	779
	Acidity Destroyed									
Light application	791	650	497	724	596	752	628	708	....	....
Medium application	1 256	773	946	1 079	605	988	936	947	....	....
Heavy application	1 977	1 832	1 185	1 886	1 027	968	1 396	1 562	....	....
Net average annual loss (corrected by acidity destroyed in subsurface)									967	554

sonably trustworthy in representing the comparative effect of the high-calcium and the dolomitic materials.

The amount of residual carbonate found was, as an average, distinctly larger where dolomitic limestone had been added; that is, this form of stone was more lasting in the soil. However, notwithstanding its more lasting quality, this form of limestone was fully as effective in destroying the soil acidity as was the high-calcium limestone. In every case where high-calcium limestone had been applied, the average results showed a smaller amount of residual limestone, a larger annual loss of limestone, and less acidity destroyed. The data also show that the larger the amount of limestone applied, the more residual carbonate found, the more acidity destroyed, and the larger the loss of limestone from the surface soil.

EFFECT OF DEGREE OF FINENESS OF LIMESTONE UPON LOSS AND UPON ACIDITY

(Series 500 to 1000)

The data in Table 9 show the effect of the degree of fineness of the limestone upon the loss of limestone and upon the acidity in the surface soil. The figures are obtained by averaging the data from all plots receiving like applications of both the high-calcium and the dolomitic limestone. The results are the averages of six separate determinations from as many separate plots.

TABLE 9.—EFFECT OF DEGREE OF FINENESS OF LIMESTONE UPON LOSS OF LIMESTONE AND UPON ACIDITY IN THE SURFACE SOIL, SERIES 500 TO 1000: NEWTON FIELD, 1916

Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Fineness.....	¼ inch down	¼ to 1/10 inch	1/10 inch down	1/50 inch down	Burnt lime
Limestone Found					
Light application.....	617	1 151	631	272	392
Medium application...	1 613	2 117	1 025	659	648
Heavy application.....	3 899	4 776	3 558	3 545	1 822
Acidity Found					
Light application.....	289	356	322	450	395
Medium application...	437	222	367	468	348
Heavy application.....	75	64	110	136	56
Acidity Destroyed					
Light application.....	631	620	709	637	746
Medium application...	863	1 059	925	855	1 006
Heavy application.....	1 368	1 443	1 458	1 492	1 634
Average Annual Loss of Limestone					
Light application.....	358	208	331	482	385
Medium application...	721	523	871	995	953
Heavy application.....	1 351	1 080	1 419	1 417	1 869

In general, the finer the stone, the greater was the loss of limestone. The mill-run stone (¼ inch down) was practically as effective as any grade in destroying the acidity and in addition possessed better lasting qualities. The fine material present in this grade of stone seems to be sufficient for the immediate requirements of the soil, and the residual properties are of value in maintaining an alkaline reaction in the soil.

The annual loss of limestone from the surface soil, calculated from the residual carbonate and the acidity destroyed, was very high where the heavy application of limestone had been made, especially where the burnt lime had been used. It was therefore thought worth while to make some determinations of the total calcium to ascertain whether the actual loss of calcium was as large as these calculations indicated, or whether the apparent loss was due, in part at least, to the retention of the calcium in some form not shown by the method used or to the decomposition of the carbonate by the acidity which had been produced in the soil since the addition of the limestone. The calcium carbonate equivalent, as determined by the total calcium, is recorded in Table 10 for a few of the plots studied.

TABLE 10.—EQUIVALENT CALCIUM CARBONATE AS CALCULATED FROM THE DETERMINATION OF TOTAL CALCIUM, SERIES 500 TO 1000: NEWTON FIELD, 1916

Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Series	500	600	700	800	900	1000
Form of limestone	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic
Amount added, *lbs*	8 000	8 000	10 000	10 000	12 000	12 000
Plot No.	Total Lime in Soil					
13 (check)	9 645	9 385	9 510	9 645	9 630	9 742
17	16 277	12 552	18 472	12 950	20 375	13 852
18	15 765	12 102	18 245	13 755	18 590	15 340
19 (check)	9 925	10 175	10 012	9 125	9 657	11 000
Plot No.	Excess Lime in Treated Plots Over That in Check Plots[1]					
17	6 446	2 640	8 627	3 652	10 727	3 271
18	5 887	2 058	8 317	4 544	8 938	4 550

[1]These calculations are based upon the assumption that the original content of the treated plots lying between the two check plots varied uniformly from one plot to the next.

The annual loss of limestone from these plots, as calculated both from the carbon dioxid and from the total calcium determination, is recorded in Table 11. In calculating the loss of dolomitic limestone it has been assumed that such limestone contains 54 percent pure calcium carbonate based upon the theoretical composition of dolomitic limestone. From a study of these data it may be seen that the actual loss of calcium was considerably lower than is indicated when the calculation

TABLE 11.—ANNUAL LOSS OF LIMESTONE AS CALCULATED FROM CARBON DIOXID AND FROM TOTAL CALCIUM, SERIES 500 TO 1000: NEWTON FIELD, 1916

Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 6⅔ to 20 inches deep)

Amount of limestone added, *lbs.*.	8,000		10,000		12,000		Average (10,000)	
	Calculated from—		Calculated from—		Calculated from—		Calculated from—	
	Carbon dioxid	Total calcium	Carbon dioxid	Total calcium	Carbon dioxid	Total calcium	Carbon dioxid	Total calcium
High-Calcium Limestone Treatment								
Plot No.	Series 500		Series 700		Series 900		Average of series	
17	1 471	444	1 437	392	1 903	364	1 604	400
18	1 426	604	2 017	481	2 199	875	1 881	653
Dolomitic Limestone Treatment								
Plot No.	Series 600		Series 800		Series 1000		Average of series	
17	1 253	889	416	925	2 025	1 697	1 231	1 170
18	1 462	1 197	1 741	454	2 371	1 021	1 858	891

is based upon the carbon dioxid determination. The average annual loss of limestone from the six high-calcium plots, as calculated from the carbon dioxid, was 1,742 pounds, while as calculated from the total calcium it was only 526 pounds. In the dolomitic series the average annual loss, as calculated from the carbon dioxid, was 1,545 pounds, while as calculated from the total calcium it was only 1,030 pounds. As an average of results from both high-calcium and dolomitic materials, the annual loss from the ground-limestone plot (No. 17), calculated from the carbon dioxid, was 1,417 pounds and from the burnt-lime plot (No. 18) 1,869 pounds; but when based upon total calcium, the loss was 785 pounds from ground limestone and 772 from burnt lime. These results indicate that the calcium was not removed from the soil more largely when applied in the form of burnt lime than when applied in the form of ground limestone.

INFLUENCE OF APPLICATIONS OF LIMESTONE TO SURFACE SOIL UPON ACIDITY IN THE SUBSURFACE AND SUBSOIL

(Series 500 to 1000)

The data for limestone and for acidity in the subsurface and the subsoil of Series 500 to 1000 are recorded in Tables 12 and 13. In general, the subsurface was found to be distinctly acid. It is very doubtful whether any of the small amounts of limestone found occasionally were due to the surface applications. Investigation showed that where limestone was found in the subsoil it extended in some

TABLE 12.—EFFECT OF LIMESTONE ON SUBSURFACE, SERIES 500 TO 1000: NEWTON FIELD, 1918

Average pounds calcium carbonate in 4 million pounds of subsurface (one acre about 6⅔ to 20 inches deep)

Series			500	600	700	800	900	1000	500	600	700	800	900	1000
	Limestone applied to surface		Limestone found						Acidity found					
Plot No.	Degree of fineness	Yearly, *lbs.*	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic
1	No lime	....	...	....	...	...	...	...	5 536	5 436	3 468	2 764	4 912	6 496
2	¼ inch down	500	...	72	62	74	464	...	4 648	4 780	2 452	3 136	6 388	7 584
3	¼ to 1/10 inch	500	...	208	166	...	...	220	4 256	3 104	3 260	4 072	7 384	5 504
4	1/10 inch down	500	...	316	...	78	...	...	4 548	512	3 992	3 836	7 584	6 296
5	1/50 inch down	500	172	....	370	...	228	...	5 072	844	3 956	5 848	7 168	5 792
6	Burnt lime	500	...	1 920	...	74	76	...	7 120	1 680	4 768	4 900	5 488	6 368
7	No lime	....	...	....	...	...	...	...	7 148	2 112	4 980	5 012	3 248	5 152
8	¼ inch down	1 000	220	76	...	2 704	322	390	5 148	2 120	504	892	4 864	4 998
9	¼ to 1/10 inch	1 000	220	212	...	...	...	186	7 636	2 684	5 272	6 892	3 848	3 524
10	¼ inch down	1 000	728	76	...	...	150	118	6 632	1 152	7 936	7 460	4 912	5 148
11	1/50 inch down	1 000	...	212	...	896	...	50	5 284	1 112	7 172	6 152	4 268	5 604
12	Burnt lime	1 000	...	312	...	...	...	426	7 772	756	5 172	5 876	3 256	3 296
13	No lime	....	...	....	...	...	...	...	7 128	2 410	5 768	7 108	3 188	6 928
14	¼ inch down	2 000	152	222	...	272	...	562	6 436	3 436	3 836	5 832	2 372	5 504
15	¼ to 1/10 inch	2 000	...	286	...	1 320	922	254	7 336	5 000	4 160	4 816	2 124	9 380
16	¼ inch down	2 000	612	150	...	404	138	390	8 428	3 924	5 308	5 144	2 088	6 912
17	1/10 inch down	2 000	440	150	...	574	...	50	10 808	5 084	3 452	5 104	3 984	3 912
18	Burnt lime	2 000	152	....	...	404	434	...	9 720	5 960	1 944	5 020	5 352	980
19	No lime	....	...	....	...	...	...	...	6 296	7 524	3 676	6 772	6 444	6 508
Average for unlimed plots									6 527	4 370	4 473	5 414	4 448	5 776
Average for limed plots									6 723	2 810	4 212	4 999	4 739	5 386
Acidity destroyed									(−196)	1 560	261	415	−291	385

TABLE 13.— EFFECT OF LIMESTONE ON SUBSOIL, SERIES 500 TO 1000: NEWTON FIELD, 1916

Average pounds calcium carbonate in 6 million pounds of subsoil (one acre 20 to 40 inches deep)

Series			500	600	700	800	900	1000	500	600	700	800	900	1000
	Limestone applied to surface		Limestone found						Acidity found					
Plot No.	Degree of fineness	Yearly, *lbs.*	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic	High-calcium	Dolomitic
1	No lime	...	930	None	672	None	1 854	924	24 144	20 292	19 848	None	None	246
2	¼ inch down	500	234	None	462	3 936	2 532	None	19 302	11 838	17 562	None	432	20 262
3	¼ to 1/10 inch	500	570	936	1 128	8 052	None	None	18 108	1 806	19 308	None	24 408	28 344
4	1/10 inch down	500	2 232	20 046	None	5 634	None	None	6 378	None	19 362	None	32 520	27 660
5	1/50 inch down	500	2 484	33 264	666	666	366	462	5 874	None	3 930	2 532	29 880	24 306
6	Burnt lime	500	3 726	23 688	2 478	None	5 688	228	312	None	312	23 190	618	20 796
7	No lime	...	8 292	27 282	1 446	None	6 150	None	3 018	None	1 146	25 248	804	23 604
8	¼ inch down	1 000	2 688	15 042	672	936	None	462	5 556	None	10 008	27 480	13 158	20 676
9	¼ to 1/10 inch	1 000	936	17 202	None	930	462	462	15 810	None	4 764	28 578	13 980	28 890
10	1/10 inch down	1 000	3 570	14 112	234	None	1 542	462	12 090	None	2 196	24 432	60	19 626
11	1/50 inch down	1 000	None	9 702	2 322	None	3 240	None	14 358	None	126	20 346	None	None
12	Burnt lime	1 000	None	45 192	5 178	None	3 450	924	18 228	None	60	16 038	None	None
13	No lime	...	None	3 528	6 774	None	12 216	1 392	23 058	None	126	19 290	None	None
14	¼ inch down	2 000	None	10 008	7 740	462	5 916	876	25 464	None	None	18 132	None	246
15	¼ to 1/10 inch	2 000	672	1 860	2 694	462	9 780	1 764	28 680	186	None	23 880	None	12 906
16	¼ inch down	2 000	672	1 440	3 306	None	12 948	2 178	24 234	126	126	19 668	None	6 072
17	1/50 inch down	2 000	672	930	4 494	666	7 458	3 192	21 852	1 086	186	16 806	None	None
18	Burnt lime	2 000	228	462	1 128	462	924	13 026	18 426	13 181	None	16 992	432	None
19	No lime	...	234	462	666	462	1 128	462	24 756	21 096	None	20 460	15 360	1 794

cases into the lower part of the subsurface, while the upper part of the subsurface was acid.

The subsurface soil of Plot 607 was sampled in three strata. The results show that per million pounds the stratum extending from 6⅔ to 14 inches below the surface contained 310 pounds of limestone and would have required 1,150 to neutralize the acidity present; while the stratum extending from 14 to 17 inches contained 200 pounds of limestone and would have required 320 pounds to neutralize the acidity; and the stratum extending from 17 to 20 inches contained 260 pounds of limestone and was neutral in reaction.

The results for the subsoil show clearly that in certain areas this stratum is distinctly acid, while in other areas an abundance of limestone is naturally present. The limestone present in the subsoil is native and not the result from any soil treatment. Examinations of the subsoil by three-inch strata show that the limestone usually increases with depth.

Thus, an examination of Table 14 will show that Plot 607, for example, which is an unlimed plot, contained 770 pounds of limestone per acre in the first 3-inch stratum of subsoil, and that the limestone increased steadily in amount to 2,820 pounds in the fifth stratum, and then decreased slightly; while every stratum was distinctly alkaline, which shows clearly that there was no unneutralized acidity present. In most other plots studied, quite similar results were obtained. However, in some plots the amount of limestone was not sufficient to neutralize the acidity present. Thus, in Plot 813 the amount of limestone was very small, while the degree of acidity was comparatively high; but it is interesting to note that the acidity decreased with depth.

In sampling the plots, the subsoil of Plot 813 was found to be plastic in nature, and in some places seemed almost impervious to water; while the subsoil of Plot 607, which contained an abundance of lime, was very moist and granular.

TABLE 14.—LIMESTONE AND ACIDITY IN VARIOUS STRATA OF THE SUBSOIL, 1916
Average pounds calcium carbonate per million pounds of soil

Plot No.....	604	607	612	704	707	813	913
				Limestone Found			
20-24 inches.	1 730	770	840	160	160	290	240
24-27 inches...	6 120	1 490	1 430	250	170	160	790
27-30 inches...	4 950	1 880	2 200	210	210	210	1 080
30-33 inches...	3 400	2 530	3 000	160	410	1 120	2 300
33-36 inches...	3 160	2 820	3 470	170	2 030	320	3 230
36-40 inches...	2 080	1 710	1 920	160	1 247	280	2 600
				Acidity Found			
20-24 inches...	Alk.	Alk.	Alk.	2 860	2 050	5 380	Neutral
24-27 inches...	Alk.	Alk.	Alk.	4 340	1 860	4 760	Alk.
27-30 inches...	Alk.	Alk.	Alk.	4 270	1 050	4 000	Alk.
30-33 inches...	Alk.	Alk.	Alk.	3 150	290	3 290	Alk.
33-36 inches...	Alk.	Alk.	Alk.	3 900	Alk.	1 840	Alk.
36-40 inches...	Alk.	Alk.	Alk.	3 210	Alk.	350	Alk.

RESULTS FROM THE ODIN EXPERIMENT FIELD

Experimental work was begun on the Odin field in 1902. On Series 100 to 400 the rotation practiced is corn, soybeans (or cowpeas), wheat, and clover. Soybeans (or cowpeas) have been substituted for clover whenever it failed. Lime was applied uniformly to all limed plots (Nos. 3, 4, 5, 8, 9, and 10) prior to 1907, when it was decided to test the effect of different rates of liming by applying, once in four years, 2,000 pounds of ground limestone per acre to the west half of each of these plots and 4,000 pounds to the east half. Since 1907 the limestone has been applied in about this proportion once in each rotation in the fall for wheat. The rates of application, together with the dates, are given in Table 15. Plots 1 to 5 in each series are not tile-drained, while Plots 6 to 10 are tile-drained.

The plan of the Odin field is given on page 288. The half-plots are designated as east and west, tho as a matter of fact the eastern line of the field approaches northeast and southwest, following the direction of the Illinois Central railroad.

COMPARATIVE EFFECT OF LIGHT AND HEAVY APPLICATIONS OF LIMESTONE AND COMPARATIVE LOSS

(Series 100 to 400)

Samples of soil for analysis were taken in the spring of 1917. The east and the west halves of each of the limed plots were sampled separately; the unlimed plots were each sampled as a whole.

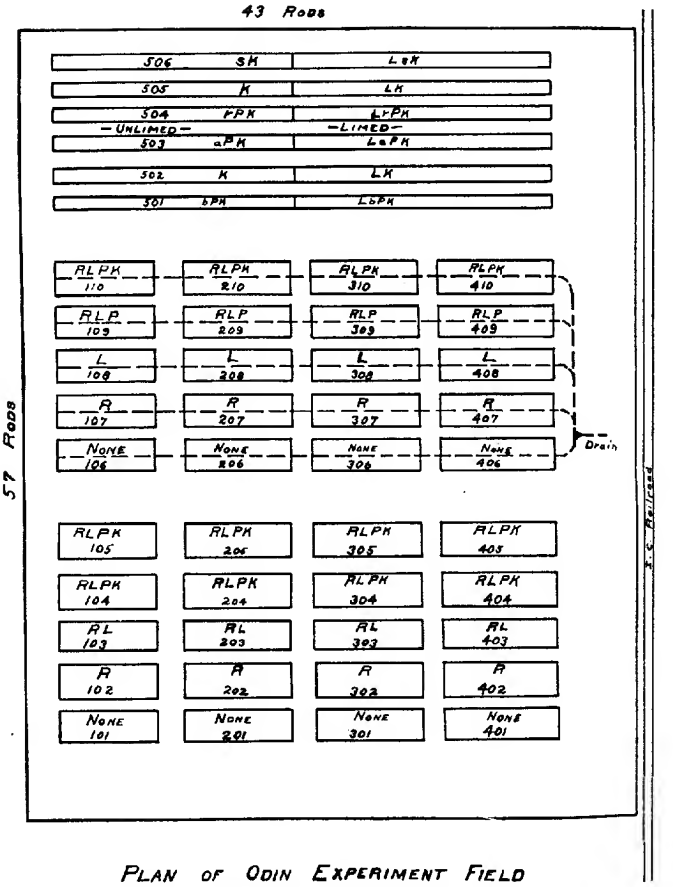
The data obtained from the surface soil are recorded in Tables 16 to 19. The results from all four series clearly show that in every case the application of either the light or the heavy amounts of limestone completely neutralized the acidity of the surface soil.

In every case where limestone had been applied, a considerable part of it was still present, and in general the amount found was proportional to the amount added. Furthermore, the limed soil was now found to be alkaline, except in four plots, three of which were neutral and the fourth but slightly acid. These exceptions all occurred where the light applications had been made. As an average of the twenty-four half-plots receiving limestone, those receiving the light applications still showed a limestone content of 1,362 pounds per acre, with an annual loss of 578 pounds; while the half-plots receiving the heavy applications showed an average content of 3,742 pounds per acre and an annual loss of 812 pounds. If limestone is added to acid soil only for the purpose of destroying the acidity of the surface soil, then the application of 2,000 pounds once in three or four years, after the initial acidity has been destroyed, would seem to be ample for keeping the soil alkaline. As an average, where the lighter applications had been made (one ton per acre once in four years), the loss (based

TABLE 15.—LIMESTONE APPLIED ON ODIN FIELD, 1902–1916
(Pounds per acre)

Series		1902[1]	1903[1]	1904	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	Total
100	E. half..	475	4 000	...	3 856	...	...	...	4 144	...	...	...	4 000	...	16 475
	W. half.	475	4 000	...	1 928	...	...	...	2 072	...	...	...	2 000	...	10 475
200	E. half..	475	4 000	...	3 800	...	...	3 000	...	...	...	1 200	4 000	...	16 475
	W. half..	475	4 000	...	1 900	...	...	1 500	...	...	...	600	2 000	...	10 475
300	E. half..	475	4 000	...	3 800	...	3 600	...	...	...	4 600	...	...	...	16 475
	W. half..	475	4 000	...	1 900	...	1 800	...	...	...	2 300	...	...	...	10 475
400	E. half..	475	4 000	...	...	3 600	...	...	...	4 000	...	...	...	4 000	16 075
	W. half..	475	4 000	...	...	1 800	...	...	...	2 000	...	...	...	2 000	10 275

[1]The applications recorded for 1902 and 1903 were of slaked lime.



PLAN OF ODIN EXPERIMENT FIELD

upon carbon dioxid) was only 75 percent as great as where the larger applications of two tons had been made.

From the data recorded in Tables 16 to 19 is computed an average annual loss from the surface soil of 812 pounds and 578 pounds, respectively, of limestone, where the heavier and the lighter applications had been made, as the average of the twenty-four limed half-plots. This loss is accounted for in part by the loss in drainage, and in part by the passing of the limestone down into the subsurface, there partially neutralizing the original acidity or even remaining as carbonate.

TABLE 16.—EFFECT OF LIMESTONE ON SURFACE SOIL, SERIES 100: ODIN FIELD, 1917
Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Plot No.	Treatment	Limestone				Soil acidity				Annual loss of limestone[2]	
		East half		West half		East half		West half			
		Added	Found	Added	Found	Found	Destroyed[1]	Found	Destroyed	East half	West half
101	0	...	...	...	...	152	...	152	...	...	...
102	R	...	...	...	...	354	...	354	...	...	...
103	RL	16 475	7 209	10 475	529	Alkaline	379	Neutral	379	576	646
104	RLP	16 475	3 429	10 475	1 489	Alkaline	379	Alkaline	379	846	577
105	RLPK	16 475	2 329	10 475	769	Alkaline	379	40	379	925	629
106	0	...	...	...	...	546	...	546	...	...	...
107	R	...	...	...	...	466	...	466	...	...	...
108	RL	16 475	3 621	10 475	2 181	Alkaline	379	Alkaline	379	832	529
109	RLP	16 475	3 841	10 475	1 661	Alkaline	379	Alkaline	379	816	565
110	RLPK	16 475	3 701	10 475	2 381	Alkaline	379	Alkaline	379	827	514

[1]Based upon the average of the unlimed Plots 1, 2, 6, and 7.
[2]In calculating the annual loss it has been assumed that the lime and limestone applied contained 95 percent pure calcium carbonate or its equivalent. The annual loss recorded is the average for fourteen years.

TABLE 17.—EFFECT OF LIMESTONE ON SURFACE SOIL, SERIES 200: ODIN FIELD, 1917
Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Plot No.	Treatment	Limestone				Soil acidity				Annual loss of limestone	
		East half		West half		East half		West half			
		Added	Found	Added	Found	Found	Destroyed	Found	Destroyed	East half	West half
201	0	...	...	...	...	312	...	312	...	...	...
202	R	...	...	...	...	244	...	244	...	...	...
203	RL	16 475	3 904	10 475	774	Alkaline	313	Alkaline	313	817	633
204	RLP	16 475	2 864	10 475	1 044	Alkaline	313	Alkaline	313	891	614
205	RLPK	16 475	3 344	10 475	544	Alkaline	313	Neutral	313	857	650
206	0	...	...	...	...	454	...	454	...	...	...
207	R	...	...	...	...	244	...	244	...	...	...
208	RL	16 475	3 217	10 475	1 397	Alkaline	313	Alkaline	313	866	588
209	RLP	16 475	4 264	10 475	1 742	Alkaline	313	Alkaline	313	791	564
210	RLPK	16 475	2 542	10 475	1 922	Alkaline	313	Alkaline	313	914	551

TABLE 18.—EFFECT OF LIMESTONE ON SURFACE SOIL, SERIES 300: ODIN FIELD, 1917
Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Plot No.	Treatment	Limestone				Soil acidity				Annual loss of limestone	
		East half		West half		East half		West half			
		Added	Found	Added	Found	Found	Destroyed	Found	Destroyed	East half	West half
301	0	...	...	...	...	406	...	405	...	...	...
302	R	...	...	...	...	498	...	498	...	...	...
303	RL	16 475	3 606	10 475	986	Alkaline	675	Alkaline	675	812	592
304	RLP	16 475	3 686	10 475	786	Alkaline	675	Alkaline	675	806	606
305	RLPK	16 475	2 626	10 475	946	Alkaline	675	Alkaline	675	882	595
306	0	...	...	...	...	1 080	...	1 080	...	...	...
307	R	...	...	...	...	718	...	718	...	...	...
308	RL	16 475	2 554	10 475	1 034	Alkaline	675	Alkaline	675	887	589
309	RLP	16 475	2 994	10 475	674	Alkaline	675	Alkaline	675	856	615
310	RLPK	16 475	2 534	10 475	814	Alkaline	675	Alkaline	675	888	604

TABLE 19.—EFFECT OF LIMESTONE ON SURFACE SOIL, SERIES 400: ODIN FIELD, 1917
Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Plot No.	Treatment	Limestone				Soil acidity				Annual loss of limestone	
		East half		West half		East half		West half			
		Added	Found	Added	Found	Found	Destroyed	Found	Destroyed	East half	West half
401	0	...	...	...	...	204	...	204	...	...	...
402	R	...	...	...	...	478	...	478	...	...	...
403	RL	16 075	1 606	10 275	1 306	Alkaline	416	Alkaline	416	946	574
404	RLP	16 075	3 406	10 275	3 306	Aklaline	416	Alkaline	416	818	431
405	RLPK	16 075	6 326	10 275	2 006	Alkaline	416	Alkaline	416	609	524
406	0	...	...	...	...	456	...	456	...	...	...
407	R	...	...	...	...	426	...	426	...	...	...
408	RL	16 075	6 844	10 275	1 984	Alkaline	416	Alkaline	416	572	526
409	RLP	16 075	6 044	10 275	1 284	Alkaline	416	Alkaline	416	629	576
410	RLPK	16 075	3 324	10 275	1 144	Alkaline	416	Neutral	416	823	585

In considering the annual loss of limestone from the light and the heavy applications, the following facts should be kept in mind: (1) The initial application of limestone was made in the fall of 1902, more than fourteen years previous to sampling; and (2) during the first five or six years, equal and somewhat larger applications of lime were applied to all plots, so that the average annual application for the light and the heavy applications had been equivalent to 745 and 1,169 pounds, respectively. During the latter years of the experiment, these amounts were about 500 and 1,000 pounds, respectively. From the data obtained, the loss for the light application may be computed as 66 percent and for the heavy application 54 percent; or 60 percent as an average of both the light and heavy applications.

INFLUENCE OF APPLICATIONS OF LIMESTONE TO SURFACE SOIL UPON ACIDITY IN THE SUBSURFACE AND SUBSOIL

(Series 100 to 400)

The amount of acidity in the subsurface of these four series was found in most plots to be very high but also very irregular. In many cases considerable limestone also was found. An examination of the data recorded in Table 20 will show distinct evidence that the appli-

TABLE 20.—EFFECT OF LIMESTONE ON SUBSURFACE, SERIES 100 TO 400: ODIN FIELD, 1917

Average pounds calcium carbonate in 4 million pounds of subsurface soil (one acre about 0 to 6⅔ inches deep)

Plot No.	Limestone found		Soil acidity		Limestone found		Soil acidity	
	East half	West half	East half	West half	East half	West half	East half	West half
	Series 100				Series 200			
1	....	....	3 656	3 656	....	....	2 552	2 552
2	....	....	4 760	4 760	....	....	2 892	2 892
3	1 418	None	320	5 360	824	184	1 640	4 560
4	778	698	3 680	1 600	144	24	1 640	1 560
5	1 338	1 498	2 360	3 040	554	24	800	4 120
6	....	....	4 792	4 792	....	....	4 860	4 860
7	....	....	3 220	3 220	....	....	2 020	2 020
8	3 028	348	3 480	5 960	None	None	1 840	1 960
9	628	588	3 200	2 520	None	None	280	160
10	1 588	1 028	3 040	5 680	186	266	2 000	280
	Series 300				Series 400			
1	....	....	3 916	3 916	....	....	3 692	3 692
2	....	....	5 368	5 368	....	....	4 440	4 440
3	320	160	2 400	320	644	404	3 520	600
4	400	240	620	2 720	564	324	2 320	480
5	160	320	2 360	3 200	2 124	None	1 080	3 200
6	....	....	4 264	4 264	....	....	1 984	1 984
7	....	....	5 908	5 908	....	....	932	932
8	928	328	2 320	3 120	1 760	800	1 520	2 320
9	2 808	978	680	3 880	3 080	1 440	160	2 320
10	1 128	528	1 880	3 640	1 600	640	880	3 040

cation of limestone to the surface soil is being felt in the subsurface, since much of the acidity of the subsurface has been destroyed; but owing to the irregularity of the limestone and the acidity in the subsurface of the individual plots, it is impossible to draw very fine distinctions from a study of individual plots. However, a comparison of the averages of the sixteen untreated plots and of the twenty-four half-plots on which heavy and light applications have been made shows a distinct influence by the limestone, as indicated in Table 21.

The acidity present in the check plots was found to be very high—3,703 pounds per acre as an average of sixteen separate determinations. Where the light applications of limestone had been made to the surface soil, the average of twenty-four separate determinations showed 2,735 pounds of acidity per acre in the subsurface, or a decrease of one-fourth of the acidity, with an average of only 451 pounds of limestone present; while where the heavy applications had been made, the average acidity had decreased to 1,834 pounds, or by about one-half of that originally present, and the average limestone present averaged 1,083 pounds, or about two and one-half times the amount where the light applications had been made.

TABLE 21.—EFFECT OF LIMESTONE ON SUBSURFACE SOIL: AVERAGES OF ALL PLOTS, SERIES 100 TO 400: ODIN FIELD, 1917

Average pounds calcium carbonate in 4 million pounds of subsurface soil (one acre about 6⅔ to 20 inches deep)

Number of plots	Lime added to surface soil	Limestone found	Acidity		Limestone net gain for subsurface
			Found	Destroyed	
16 plots.....	None.....	None	3 703	.....	.....
24 half-plots....	Light application.	451	2 735	968	1 419
24 half-plots....	Heavy application	1 083	1 834	1 869	2 952

The data recorded in Table 21 indicate that as a result of the applications during fourteen years' time the sum of the limestone destroyed in neutralizing acidity in the subsurface and that found remaining in that stratum amounted to 2,952 pounds where the heavy applications had been made and 1,419 pounds where the light applications had been made. These figures represent an annual gain of 211 pounds and 94 pounds of limestone, respectively, in the subsurface stratum. If these numbers be subtracted from the annual loss from the surface soil, the unaccounted annual loss from that stratum amounts to 601 pounds and 484 pounds, respectively, for the heavy and the light applications.

The data for the limestone and acidity in the subsoil of these series is recorded in Table 22. The occurrence of limestone and acidity is very irregular and as one increases in amount the other decreases. The indications are that this limestone is native to the subsoil and has not been influenced at all by the applications to the surface soil.

TABLE 22.—LIMESTONE AND ACIDITY IN SUBSOIL OF SERIES 100 TO 400: ODIN FIELD, 1917

Average pounds calcium carbonate per acre in 6 million pounds of subsoil (one acre 20 to 40 inches deep)

Series		100	200	300	400	100	200	300	400
Plot No.	Treatment	Limestone found				Acidity found			
1	0.....	17 112	19 908	None	1 452	None	None	18 564	9 732
2	R.....	11 550	6 096	None	516	None	None	19 728	9 792
3	RL.....	1 500	456	11 268	462	1 854	5 202	None	954
4	RLP....	462	462	522	5 970	15 978	5 988	5 430	None
5	RLPK...	1 194	2 808	516	1 194	2 106	216	9 126	11 976
6	0.....	None	4 338	3 912	1 188	126	426	None	156
7	R.....	960	8 262	None	1 914	246	None	1 056	5 334
8	RL.....	1 374	1 182	15 468	None	396	246	None	24 126
9	RLP....	1 110	14 616	6 294	516	150	None	246	21 678
10	RLPK...	1 374	13 122	234	510	246	None	11 796	36 522

EFFECT OF DRAINAGE UPON LOSS OF LIMESTONE

(Series 100 to 400)

On Series 100 to 400, one-half of the plots of each series are tile-drained while the other half are undrained. Of the plots which receive limestone, then, there are twelve drained and twelve undrained. These plots furnish an excellent opportunity for studying the effect of drainage upon the loss of limestone from this type of soil, gray silt loam on tight clay. The average results for limestone found and for the annual loss of limestone are recorded in Table 23.

These results show that there is no distinct influence from tile drainage on the loss of limestone from this type of soil.

TABLE 23.—EFFECT OF DRAINAGE UPON LOSS OF LIMESTONE, AVERAGE OF ALL UNDRAINED AND DRAINED LIME-TREATED PLOTS, SERIES 100 TO 400: ODIN FIELD, 1917

Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Number of plots	Total limestone applied, average pounds per acre	Undrained		Drained	
		Limestone found	Annual loss	Limestone found	Annual loss
12	10 425	1 207	589	1 517	567
12	16 375	3 694	814	3 790	808

LIMESTONE AND ACIDITY IN SERIES 500

On Series 500 a five-year rotation of corn, oats, and three crops of hay (clover and timothy) is practiced. Altho this series is devoted primarily to a phosphate test, the east half of each plot is limed while the west half is not limed, so that limestone data are furnished as well as phosphate. The limed halves of these plots have received a total application of 11,000 pounds of limestone: 3,000 pounds in 1904, 3,600 pounds in 1909, and 4,400 in 1914.

The data for limestone and acidity in the surface soil, obtained in 1916, are recorded in Table 24.

TABLE 24.—EFFECT OF LIMESTONE ON SURFACE SOIL, SERIES 500: ODIN FIELD, 1916

Average pounds calcium carbonate in 2 million pounds of surface soil (one acre about 0 to 6⅔ inches deep)

Plot No.		Treatment	Limestone		Soil acidity		Annual loss of limestone
			Added	Found	Found	Destroyed	
501	E	LK bone P.....	11 000	1 694	Alkaline	294	819
	W	K bone P.....	.....	.....	294	.....	....
502	E	LK.....	11 000	2 808	Alkaline	1 348	622
	W	K.....	.....	.....	1 348	.....	....
503	E	LK acid P.....	11 000	1 962	Alkaline	1 450	690
	W	K acid P.....	.....	.....	1 450	.....	....
504	E	LK rock P.....	11 000	1 758	Alkaline	810	766
	W	K rock P.....	.....	.....	810	.....	....
505	E	LK.....	11 000	1 266	42	1 852	716
	W	K.....	.....	.....	1 894	.....	....
506	E	LK slag P.....	11 000	2 214	Alkaline	334	768
	W	K slag P.....	.....	.....	334	.....	....

In every case where limestone had been applied some of it could still be found in the surface. In only one of the limed half-plots was there any acidity found and then only 42 pounds per acre, while in all the other limed areas the soil was distinctly alkaline. Large amounts of acidity had been neutralized in all the limed plots. The annual loss of limestone varied from 622 pounds per acre to 819 pounds.

The data for the acidity and limestone in the subsurface of Series 500 is found in Table 25. It is evident that the average acidity of this stratum was greater in this part of the Odin field than in any other part. The application of limestone to the surface apparently resulted in the neutralization of considerable of the acidity in the subsurface. This conclusion is confirmed by a study of the results obtained from the subsoil (Table 26), where it may be seen that the subsoil of the limed part of the plots was more acid than that of the unlimed portion, clearly indicating that the limestone present in the subsurface resulted from the applications to the surface and was not derived from native limestone.

In Table 26 are recorded the data for the subsoil of Series 500. The subsoil of the limed portion of the plots was found to be distinctly more acid than that of the unlimed portion. In fact, in half of the cases the subsoil of the unlimed plots contained no acidity but con-

TABLE 25.—EFFECT OF LIMESTONE ON SUBSURFACE, SERIES 500: ODIN FIELD, 1916

Average pounds calcium carbonate in 4 million pounds of subsurface (one acre about 6⅔ to 20 inches deep)

Plot No.		Treatment applied to surface soil	Limestone		Soil acidity	
			Added to surface soil	Found	Found	Destroyed
501	E	LK bone P.	11 000	None	1 596	5 744
	W	K bone P.	.....	.....	7 340	.....
502	E	LK.	11 000	None	1 348	2 900
	W	K.	.....	.....	4 248	.....
503	E	LK acid P.	11 000	472	2 324	3 460
	W	K acid P.	.....	.....	5 784	.....
504	E	LK rock P.	11 000	None	3 824	None
	W	K rock P.	.....	.....	3 628	.....
505	E	LK.	11 000	None	3 848	None
	W	K.	.....	.....	3 720	.....
506	E	LK slag P.	11 000	300	648	680
	W	K slag P.	.....	.....	1 328	.....

TABLE 26.—EFFECT OF LIMESTONE ON SUBSOIL, SERIES 500: ODIN FIELD, 1916

Average pounds calcium carbonate in 6 million pounds of subsoil (one acre 20 to 40 inches deep)

Plot No.		Treatment applied to surface soil	Limestone		Soil acidity
			Added	Found	Found
501	E	LK bone phosphate.	11 000	2 946	19 296
	W	K bone phosphate.	.....	1 194	648
502	E	LK.	11 000	None	30 402
	W	K.	.....	2 430	282
503	E	LK acid phosphate.	11 000	252	23 160
	W	K acid phosphate.	.....	1 500	336
504	E	LK rock phosphate.	11 000	1 188	30 948
	W	K rock phosphate.	.....	10 014	None
505	E	LK.	11 000	None	22 320
	W	K.	.....	12 864	None
506	E	LK slag phosphate.	11 000	462	21 408
	W	K slag phosphate.	.....	6 240	None

siderable limestone, while the subsoil of the limed plots contained an amount of acidity that would have required several thousand pounds of limestone to neutralize it. Therefore, the reduced acidity and the limestone found in the subsurface of some of the limed plots must have resulted from the surface application.

CONCLUSIONS

1. From the evidence thus far secured, it appears that for the common prairie land of southern Illinois an application of one ton per acre of limestone once in three or four years is sufficient to keep the soil alkaline, or sweet, after the initial acidity has been destroyed by heavier applications.

2. Dolomitic limestone can be used successfully on acid soils. It is slightly more effective than high-calcium limestone in neutralizing the soil acidity, is more durable, and has no injurious effects on the crop yields.

3. As the result of nearly four years' work on the Newton field, there is no evidence that finely ground limestone is more effective in correcting soil acidity than is the total product from a ¼-inch screen, which contains both the finer material for immediate use and the coarser material for greater durability. This "mill-run" product seems to be the most economical form to use; but final conclusions must await further data concerning crop yields.

4. The destruction of the acidity of the soil is not a rapid process, for it is dependent upon the complete mixing of the applied limestone with the surface soil, which is a slow process. Limestone applied to the surface slowly penetrates into the subsurface. This process, however, requires considerable time. On the Odin field after fourteen years, one-half the acidity in the subsurface was neutralized where the larger applications had been made to the surface, and one-fourth where the lighter applications had been made. Applications of limestone to the surface soil seem to have no effect upon the acidity of the subsoil. The amount of native limestone found in the subsoil is a variable quantity. In some cases there is none present even at a depth of forty inches, whereas in other cases it extends upward even slightly into the subsurface.

5. The annual loss of limestone from the soil depends upon a number of factors, among which are the kind, the form, and the amount added. The data presented show that the annual loss of limestone is not so large as is generally assumed. As an average of all determinations, the annual loss from the surface twenty inches was 760 pounds per acre from the Newton field and 542 pounds per acre from the Odin field. A study of the total calcium indicates that the actual loss of bases may have been less than is shown by these figures, which are based upon the carbon dioxid and acidity determinations.

6. It is very evident from the data presented that chemical analysis may be depended upon to measure the acidity in the soil, the reduction in acidity due to the action of limestone applied, and also to find the limestone still remaining in the soil, whether from applications made or from a supply native to the soil.